

An Improved Black Hole Mass–Bulge Luminosity Relationship for AGNs

C. Martin Gaskell and John Kormendy

*Astronomy Department, University of Texas, Austin, TX 78712-0259,
 USA*

Abstract. Two effects have substantially increased the scatter in the AGN black hole mass–host galaxy bulge luminosity relationship derived from SDSS spectra. The first is that at a fixed black hole mass, M_\bullet , the SDSS spectrum depends strongly on redshift because an SDSS fiber sees a larger fraction of the total light of more distant galaxies. The second is that at a given redshift, the fraction of host-galaxy light in the fiber increases with decreasing galaxy luminosity. We illustrate the latter effect using the Kormendy et al. (2009) light profiles of Virgo ellipticals. With allowance for the two effects, we obtain a black hole mass–bulge luminosity ($M_\bullet - L_{host}$) relationship for AGNs which has a scatter of only ± 0.23 dex in mass. This is less than the scatter found for inactive galaxies, and is consistent with the measuring errors. We show that there is a corresponding tight linear relationship between the fraction of host galaxy light in AGN spectra, L_{host}/L_{AGN} , and the Eddington ratio, L/L_{Edd} . This linearity implies that at a given M_\bullet , host luminosities of high-accretion-rate AGNs (NLS1s) and low-accretion-rate AGNs are similar. The $L_{host}/L_{AGN} - L/L_{Edd}$ relationship provides a simple means of estimating the fraction of host galaxy light in AGN spectra. This means that the real amplitude of variability of low-accretion-rate AGNs is increased relative to NLS1s.

1. Introduction

It has long been recognized that the masses, M_\bullet , of supermassive black holes (SMBHs) are proportional to the stellar luminosities, L_{host} , of the bulges of the galaxies in which they are located (see Kormendy & Richstone 1995 and Kormendy & Gebhardt 2001 for reviews). M_\bullet can be most easily determined for AGNs. Dibai (1977) showed that M_\bullet can be estimated for an AGN from the broad emission lines in a single-epoch spectrum, so long as the broad-line region (BLR) motions are gravitationally dominated. Reverberation mapping has verified that the BLR motions are dominated by gravity (Gaskell 1988) and has confirmed the accuracy of the Dibai method (see Bochkarev & Gaskell 2009). With the advent of the SDSS, the Dibai method has been used to estimate the masses of tens of thousands of black holes. Shen et al. (2008) give masses for 900 SDSS AGNs for which Vanden Berk et al. (2006) have spectroscopically estimated L_{AGN}/L_{host} , the ratio of AGN light to host galaxy light at 5100 Å in the rest frame. In this paper we use these data to study the dependence of L_{AGN}/L_{host} on the accretion rate (which we will express by the Eddington ratio, L/L_{Edd}) and to obtain an improved $M_\bullet - L_{host}$ relationship.

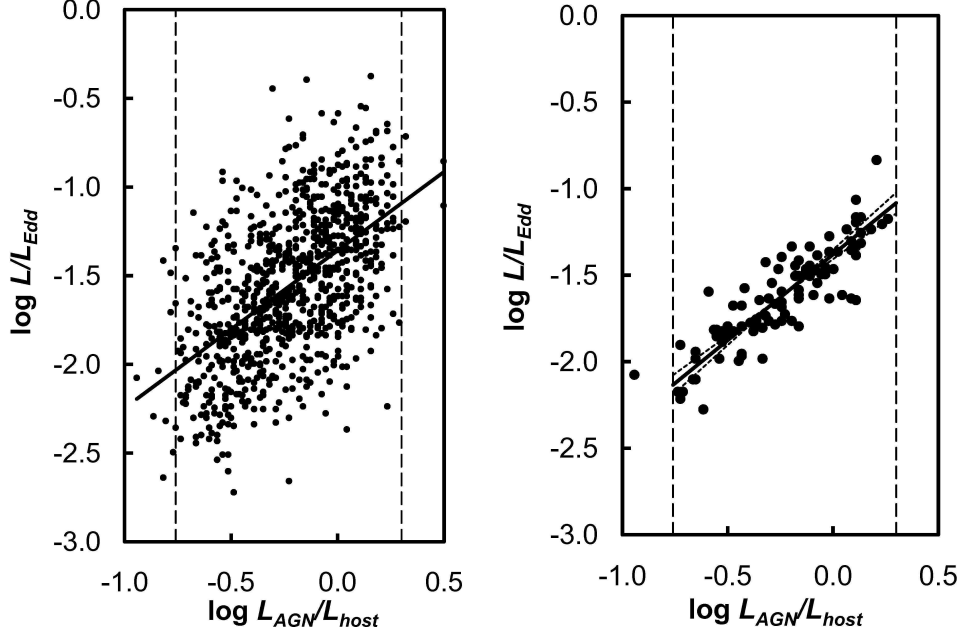


Figure 1. Eddington ratios, L/L_{Edd} , as a function of L_{AGN}/L_{host} , the ratio of AGN flux to host galaxy flux at 5100 \AA . The dashed vertical lines show the approximate upper and lower cutoffs of Shen et al. (2008). (a) (left panel) shows all low-redshift ($z < 0.45$) SDSS AGNs in the sample. The diagonal line is a linear regression on $\log L_{AGN}/L_{host}$. (b) (right panel) shows just 100 AGNs with $\log M_{bh} = 7.7 \pm 0.2$, and $0.13 < z < 0.18$. The solid diagonal line is a censored OLS-bisector fit (Isobe et al. 1990), and the 68% confidence interval for the slope is shown by the two dotted lines.

2. Results

Fig. 1a shows L_{AGN}/L_{Edd} as a function of L_{AGN}/L_{host} . Because of difficulties in measuring L_{AGN}/L_{host} when the AGN is too bright or too faint compared with the galaxy, upper and lower cutoffs on the ratio have been imposed by Shen et al. (2008). Since L_{AGN} appears on both axes and since $M_{\bullet} \sim L_{host}$, we expect a simple linear correlation between L/L_{Edd} and L_{AGN}/L_{host} . Fig. 1a does indeed show a correlation, but the scatter is very large. This scatter could be a consequence of measurement errors, or it could reflect intrinsic scatter in the $M_{\bullet} - L_{host}$ relationship.

In Fig. 2a we show that if we take a narrow range of M_{\bullet} , then the luminosity deviation, $\Delta \log L_{host}$, from the diagonal line in the left panel of Fig. 1 is a strong function of redshift. This has a simple explanation: at low redshift an SDSS fiber is only taking in a small part of the bulge of the host galaxy, so the luminosity of the bulge is underestimated for nearby galaxies. Fig. 2b uses the Kormendy et al. (2009) photometry of Virgo ellipticals to show that at a given redshift, the fraction of total bulge light in an SDSS fiber decreases as the luminosity of the galaxy increases. The combination of the two effects will be discussed in detail elsewhere (Gaskell & Kormendy, in preparation), but the dramatic improvement in the $L/L_{Edd} - L_{AGN}/L_{host}$ relationship can be

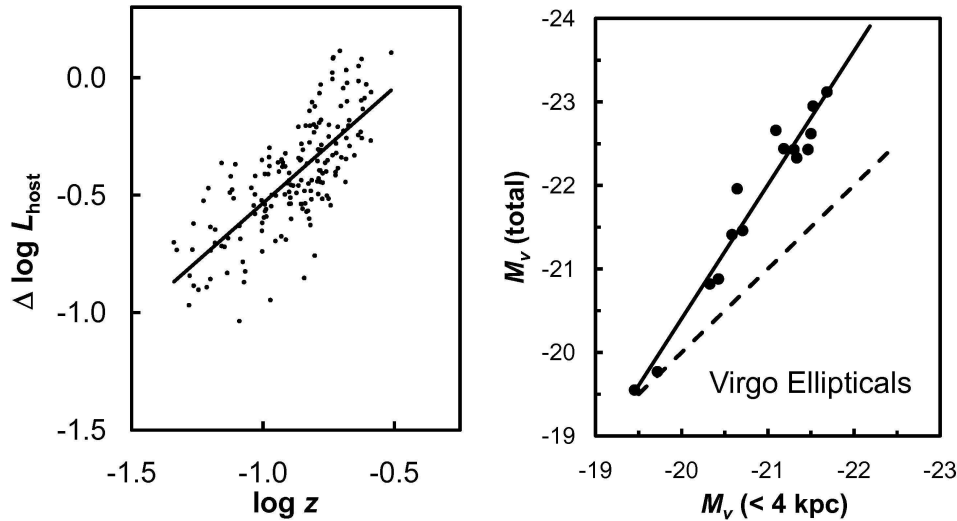


Figure 2. (a) estimated relative deficit, $\Delta \log L_{host}$, of host galaxy light at $\lambda 5100$ as a function of redshift for AGNs with $7.4 < \log M_{\bullet} < 7.6$. $\Delta \log L_{host}$ is normalized to $\log z = -0.4$. The diagonal line is a linear regression on $\log z$. (b) The total absolute magnitudes of Virgo ellipticals (derived from Kormendy et al. 2009) as a function of the absolute magnitude measured within a fixed 4 kpc radius aperture. The solid line is a linear regression of the total magnitude on the 4 kpc magnitude. The dashed line shows what the relationship would be if all the light were within 4 kpc.

illustrated simply by plotting AGNs in a narrow range of z and black hole mass. This is shown in Fig. 1b.

Fig. 3 shows the resulting $M_{\bullet} - L_{host}$ relationship for AGNs over a narrow redshift range. L_{host} has been approximately corrected using the relationship for the Virgo ellipticals in Fig. 2b. The dispersion in mass in Fig. 3 is ± 0.23 dex which is better than the ± 0.30 dex dispersion Häring & Rix (2004) found for the $M_{\bullet} - L_{host}$ relationship for non-active galaxies. Applying the luminosity correction from Fig. 2b also increases the slope of $M_{\bullet} - L_{host}$ relationship for the SDSS AGNs. If we take an $M_{\bullet} - L_{host}$ relationship of the form $M_{\bullet} \propto L_{host}^{\alpha}$, then for the complete uncorrected Shen et al. (2008) sample (not shown), an OLS-bisector fit gives a slope of $\alpha = 0.69 \pm 0.02$, while a similar fit for the corrected subset of 100 AGNs in Fig. 3 gives $\alpha = 0.84 \pm 0.03$. If we take the luminosity-dependence of the mass/light ratio of bulges to be $M/L \propto L^{0.32 \pm 0.04}$ (Cappellari et al. 2006), then $M_{bulge} \propto M_{\bullet}^{1.16 \pm 0.07}$.

3. Discussion

The small dispersion in the AGN $M_{\bullet} - L_{host}$ relationship in Fig. 3 implies that the intrinsic relationship must be very tight (as tight as the $M_{\bullet} - \sigma_{*}$ relationship), since much or all of the scatter can be accounted for by observational errors. The small dispersion also supports the reliability of AGN black hole masses determined via the Dibai method. As discussed in Bochkarev & Gaskell (2009), this implies that for the AGNs for which the method has been used,

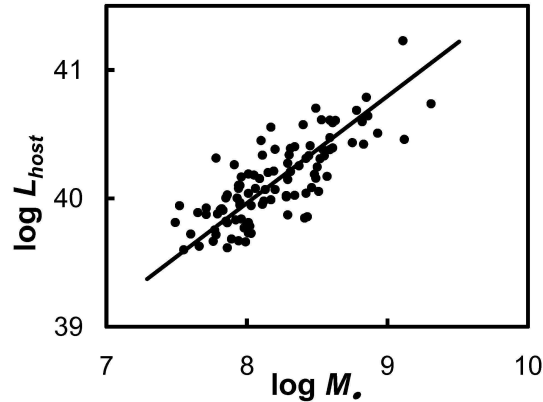


Figure 3. The $M_{\bullet} - L_{host}$ relationship for 100 AGNs restricted to $0.13 < z < 0.34$ and with L_{host} corrected for the aperture effect. The diagonal line is the OLS-bisector fit, $M_{\bullet} \propto L_{host}^{0.84}$.

both the structure and intrinsic spectral energy distributions are very similar (Gaskell et al. 2004; Gaskell & Benker 2009). The slope in Fig. 1b (0.99 ± 0.11) shows that the hosts of high-accretion-rate AGNs do not systematically deviate from the $M_{\bullet} - L_{host}$ relationship.

Fig. 1b makes determination of host-galaxy contamination of AGN photometry and spectroscopy straight forward. One immediate result is to show that low L/L_{Edd} AGNs must have greater optical variability amplitudes on average than high L/L_{Edd} AGNs (NLS1s). Klimek et al. (2004) have already shown that even without corrections for host galaxy contamination, NLS1s seem to be less variable than non-NLS1s. Fig. 1b shows that this difference will be much greater when the higher galaxy contamination of non-NLS1s is allowed for.

Acknowledgments. This research has been supported through NSF grants AST 08-03883 (MG) and AST06-07490 (JK).

References

- Bochkarev, N. G., & Gaskell, C. M. 2009, *Ast. Lett.*, 35, 287
- Cappellari, M., et al. 2006, *MNRAS*, 366, 1126
- Dibai, É. A. 1977, *Soviet Astron. Lett.*, 3, 1
- Gaskell, C. M. 1988, *ApJ*, 325, 114
- Gaskell, C. M. & Benker, A. J. 2009, *ApJ*, submitted [arXiv:0711.1013]
- Gaskell, C. M., Goosmann, R. W., Antonucci, R. R. J., & Whysong, D. H. 2004, *ApJ*, 616, 147
- Häring, N., & Rix, H.-W. 2004, *ApJ*, 604, L89
- Isobe, T., Feigelson, E. D., Akritas, M. G., Babu, G. J., 1990, *ApJ*, 364, 104
- Klimek, E. S., Gaskell, C. M., Hedrick, C. H. 2004, *ApJ*, 609, 69
- Kormendy, J., Fisher, D. B., Cornell, M. E., & Bender, R. 2009, *ApJS*, 182, 216
- Kormendy, J. & Gebhardt, K. 2001, in *20th Texas Symposium on Relativistic Astrophysics*, ed. J. C. Wheeler and H. Martel. AIP Conf. Proc., 586, 363
- Kormendy, J. & Richstone, D. O. 1995, *ARA&A*, 33, 581
- Shen, J.-J., Vanden Berk, D. E., Schneider, D. P., & Hall, P. B. 2008, *AJ*, 135, 928
- Vanden Berk, D. E. et al. 2006, *AJ*, 131, 84